

Interferential current therapy

G. C. Goats, PhD, MCSP

Department of Physiotherapy, The Queen's College, Glasgow

Introduction

Therapists often use transcutaneous electrical stimulation to treat their patients. They can select alternating current of various frequencies or direct current applied continuously or as a train of pulses. Each type of current has both advantages and disadvantages when used therapeutically.

Direct current and low-frequency alternating currents (> 1 kHz) encounter a high electrical resistance in the outer layers of the skin. This makes the treatment of deep structures painful because a large transcutaneous current must flow so that adequate current passes deeply. Alternating currents of medium (> 1 kHz to < 10 kHz) or high frequency (> 10 kHz) meet little resistance (due to a marked reduction in the effects of skin capacitance upon current flow) and penetrate the tissues easily, although such currents generally oscillate too rapidly to stimulate the tissues directly¹⁻³.

These difficulties were overcome in the early 1950s with the development of interferential current therapy. The equipment produces two alternating currents of slightly differing medium frequency and is used widely to induce analgesia, elicit muscle contraction, modify the activity of the autonomic system, promote healing, and reduce oedema³⁻⁵.

Use of interference effects in therapy

When two or more sinusoidal currents alternate at the same frequency, rising and falling at exactly the same time, they are said to be in phase. Waves become out of phase when they are a half wavelength out of step and the rising segment of one coincides with the falling segment of the other. Waves in phase interfere constructively to produce a resultant wave with an amplitude greater than that of either of the originals. Waves out of phase interact in a similar way but interfere destructively to cancel each other out (Figure 1).

Interference also occurs between waves of slightly differing frequency. As one wave peak 'catches up' with the other, constructive interference causes an increase in the amplitude of the resultant wave,

which declines subsequently as the waves again drift out of phase and interfere destructively. The rate at which the amplitude of the resultant rises and falls is equal to the difference in frequency present between the two original waves and is called a 'beat frequency'. This process is an example of amplitude modulation⁵.

Interferential current therapy exploits this principle of interference to maximize the current permeating the tissues whilst reducing to a minimum unwanted stimulation of cutaneous nerves.

The principal components of an interferential unit, illustrated in Figure 2, are a pair of signal generators, the output of one oscillating at the fixed frequency of 4000 Hz whilst the other is variable in frequency between 4000 and 4250 Hz. These signals are then amplified to a therapeutically useful intensity. The

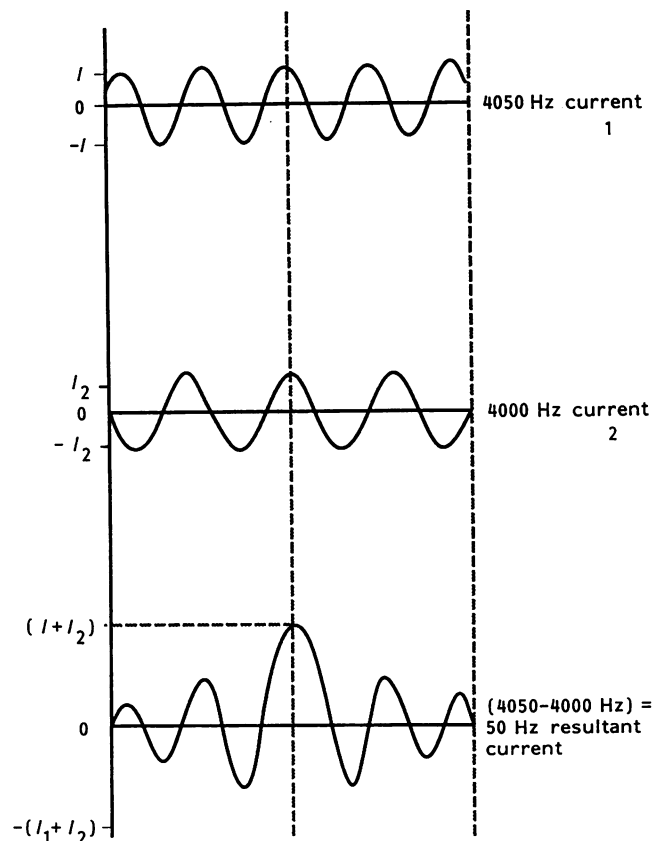


Figure 1. Amplitude modulation of alternating currents by interference

Address for correspondence: G. C. Goats PhD, MCSP, Department of Physiotherapy, The Queen's College, 1 Park Drive, Glasgow G3 6LP, UK

© 1990 Butterworth-Heinemann Ltd
0306-4179/90/020087-06



Figure 2. An interferential therapy unit with vacuum and flexible carbon rubber electrodes

variable-frequency oscillator can sweep automatically between one pre-set frequency and another, thus producing a range of beat frequencies that yield several therapeutic effects, all of which may be obtained with a single application⁴.

Two pairs of electrodes, conveying separately the amplified output of the oscillators, are aligned on the skin so that the currents flowing between each pair intersect and interfere within the structure to be treated. A resultant current of low frequency is generated that alternates at 0–250 Hz. The precise frequency will depend upon the difference that exists between the frequencies of the original currents. The beat frequency current flows maximally in the region of maximum interference that develops along diagonals extending at 45° to the direct paths between the two sets of electrodes (*Figure 3*). A snowflake-shaped field is created because one current flows

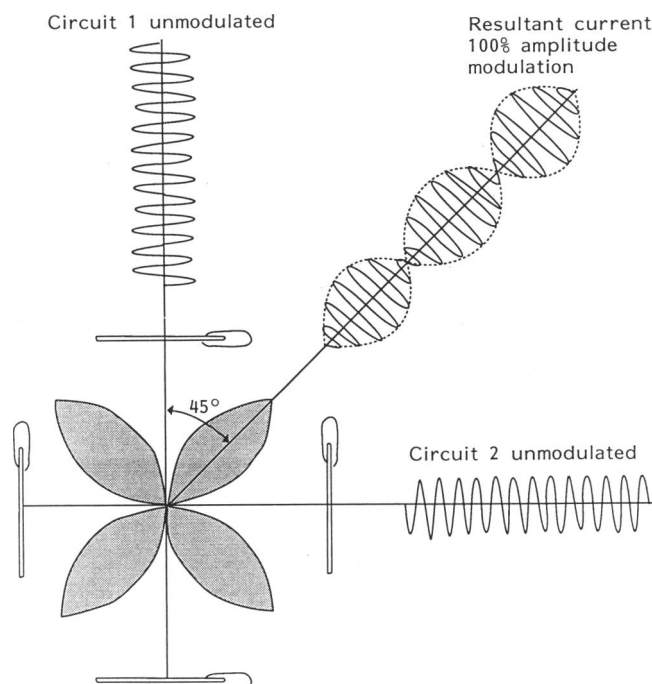


Figure 3. Pattern of interference current and degree of interference produced during a quadripolar application (by permission of Ehrf–Nonius, Delft, The Netherlands, see ref. 1)

laterally from its direct path to interact with the adjacent current. This region of maximal therapeutic effect is usually static and situated deep within the tissues³.

Static fields are used to treat small, well defined lesions but may miss sites of more diffuse damage. This difficulty is overcome by scanning the region of maximum interference systematically through the tissues. A voltage (and hence a current) applied to one of the pairs of electrodes, varying rhythmically in intensity with respect to the other, will influence an area that expands and recedes regularly. This causes the region of maximum interference to pan through the tissue². Most interferential units offer this as an automated facility, although all such automatic functions have a manual over-ride.

Some units allow for both currents to be applied in one circuit using a single pair of electrodes. Interference current will affect all the tissues between the electrodes and allow poorly localized lesions to be treated adequately. This area of maximum interference is, however, dispersed widely, thus reducing the therapeutic effect. The behaviour of interference currents in fluid media is considered in greater detail elsewhere⁶.

Some manufacturers offer equipment that can also operate at a base frequency of 2kHz. The interference currents so generated are of similar frequency to those produced by the interaction of currents alternating at 4kHz, although clinical practice suggests that the lower base frequency is able to stimulate muscles more effectively¹.

Recent advances in electronic design enable manufacturers to supply units that generate three-dimensional, or stereodynamic interference fields. Three currents of slightly differing medium frequency are applied via three separate electrode pairs. These interact to affect a greater volume of tissue than is possible with the more common twin-current quadripolar application⁷.

Techniques, contraindications and safety

The area of skin to be treated is cleaned with soap and water to reduce linear electrical resistance (reactance arising from capacitance is unchanged) and the electrodes are fixed to the skin with tape. Some apparatus is supplied with electrodes that are held in place by suction cups evacuated using a vacuum pump. This facility is useful when treating regions such as the trunk where it is difficult to strap an electrode. The electrodes are orientated so that the two currents intersect within the target structure. Alternatively, the therapist may wear one electrode of each pair as a glove and vary the site of maximum interference during the treatment. Some units incorporate four electrodes into a single small applicator, thus facilitating the effective treatment of superficial and localized lesions.

The intensity of the current is increased gradually until the patient reports that a further rise would cause discomfort. Cutaneous nerves accommodate rapidly to this stimulus and after a few seconds a larger current can be applied. This procedure is

repeated until no further accommodation is observed. Most patients tolerate interferential therapy well. Further explanation of the practical aspects of treatment are available in various authoritative texts^{2,4,5,8-10}.

Contraindications are few, although the prudent would not treat patients presenting with very acute inflammation, fever, tumour, thrombosis, those who are pregnant, have a marked aversion to this type of therapy, or persons wearing a cardiac pacemaker. Concern that interferential therapy might promote the aggregation of platelets and induce thrombosis appears unfounded¹¹.

This apparatus should not be used within five metres of an operational short-wave diathermy unit because the cables may act as antennae and conduct a dangerous quantity of RF energy to the patient².

Physiological and therapeutic effects of interferential currents

The current flowing between each pair of electrodes is insufficient to stimulate nerve and muscle directly until amplitude is modulated by interference. Interferential therapy thus reduces the stimulation of cutaneous sensory nerves near the electrodes whilst promoting the effect upon deep tissues.

The physiological effect of an amplitude-modulated suprathreshold current depends upon frequency. Neurons exhibit a maximum rate at which action potentials are conducted and this is a function of the degree of myelination and the diameter of the axon. Repetitive stimulation at any frequency up to its maximum (1 kHz for a large motor neuron) will cause action potentials to flow in the axon at the same rate. As the rate of stimulation increases above this value, successive stimuli fall within the relative, and eventually the absolute refractory period of the preceding action potential. A larger than normal flow of current is necessary to stimulate a refractory neuronal membrane and thus the sensitivity of the nerve decreases. This effect is termed Wedensky inhibition. Prolonged stimulation at a supramaximal frequency will eventually cause the axon to cease conducting. Accommodation of the neuron is responsible for this effect, caused by an increased threshold and synaptic fatigue¹². Some sources report that these effects occur in large neurons stimulated at frequencies as low as 40 Hz¹³. Small or unmyelinated neurons have a slower conduction velocity and longer refractory period than large neurons and will show a stimulus-induced block to conduction at a lower frequency.

Stimulation of muscle

A neurone showing the reduced sensitivity associated with Wedensky inhibition will also have a rate of firing independent of the frequency of the applied stimulus. This rate is dictated instead by the duration of the refractory period. Known as the Gildemeister effect, rapid stimulation of a motor nerve with large although comfortable interferential currents will result in an asynchronous depolarization of indi-

vidual motor units. This mimics the pattern observed during a normal voluntary contraction. Traditional low-frequency neuromuscular stimulation tends to recruit only the large axon motor neurons, which have a lower threshold than small fibres, and innervate muscle fibres that fatigue readily. This pattern of discharge is synchronous and unlike a normal contraction.

Motor excitation using interferential currents is considered by many to represent an advance over the other low-frequency methods of stimulation. The optimum frequency of stimulation for most voluntary muscle appears to be 40–80 Hz^{5,14}, whilst visceral muscle, supplied by the autonomic nervous system, is stimulated optimally at 10–50 Hz¹⁵.

Interferential therapy can produce a torque in the quadriceps femoris greater than 50 per cent of that achieved during a maximal voluntary contraction¹⁶. This performance certainly equals that of the other methods of electrical muscle stimulation¹⁴. A favourable clinical outcome was also reported in the treatment of muscular paralysis arising from degeneration of the facial nerve¹⁷ and radial epicondylitis¹⁸.

Control of pain

The analgesic effect of interferential therapy can be explained in part by Wedensky inhibition of Type C nociceptive fibres, although other mechanisms are certainly involved. 'Pain gate' theory, proposed by Malzack and Wall¹⁹ and much modified subsequently²⁰ remains central to this explanation. Briefly, this theory proposes that action potentials travelling in large-diameter myelinated afferent nerves from cutaneous receptors compete for access to the central ascending sensory tracts in the dorsal horn of the spinal cord with those of small-diameter unmyelinated sensory fibres carrying pain information. Activity in the large fibres takes precedence over that in small fibres, 'closing the gate' to pain information entering the central nervous system and preventing it from reaching a conscious level. Pain is thus reduced. Large-diameter myelinated fibres are stimulated optimally at 100 Hz^{5,21} and clinical experience indicates that interferential therapy at this frequency reduces pain markedly, especially when applied to acupuncture points. Pain will also reduce as motor stimulation increases the circulation of body fluid and promotes an efflux of pain-inducing chemicals from the site of damage.

Another system that helps to reduce pain is the 'descending pain suppression mechanism', which is mediated by the endogenous opiates. Nociceptive information that enters the spinal cord travels to the thalamus and will interact in the mid-brain with many structures. The raphe nuclei are amongst the most important of these, and increased activity in fibres descending from the raphe nuclei to the spinal segment at which the pain information entered will release inhibitory neurotransmitters that block further conduction²². Interferential current with a frequency of 15 Hz affects these fibres maximally^{5,21}. A beat frequency varying rhythmically within a narrow range about this optimum value avoids the problem of accommodation to the stimulus^{1,4,5}. Pain

will initially intensify as this mechanism is activated by transcutaneous stimulation of Type A_δ and C fibres, although the analgesia induced subsequently appears more enduring than that achieved by recruiting the 'pain gate' system.

Interferential therapy is often applied clinically to control pain^{2,5,21} but few rigorous studies are reported that justify this use. Taylor *et al.*²³ noted that jaw pain was not controlled adequately by interferential therapy, although pain induced deliberately by immersion of a limb in iced water was rated as less severe, compared to the experience of the controls, by subjects treated previously with interferential current at 100 Hz (Goats *et al.* 1989 unpublished findings). Pain arising from sprained joints was reduced markedly by a 15 minute application of interferential therapy at a frequency varying between 0 and 100 Hz²⁴ and classical migraine responded well to treatment at 90–100 Hz for 10 minutes applied to the zygomatic arch²⁵.

The placebo effect is a potent factor in the use of an interferential therapy unit.

Autonomic effects and the control of incontinence

Type A_δ and C fibres, and those of the autonomic nervous system, are generally small and poorly myelinated. Clinical evidence suggests that these small neurons of the peripheral nervous system fail to conduct when stimulated at frequencies exceeding 40 and 15 Hz respectively²¹. When extrapolated to the autonomic nervous system, this behaviour can be exploited therapeutically^{5,26} by using the stimulus of an interferential current to reproduce by non-invasive means the vasodilatation caused by chemical sympathectomy in peripheral vascular disease and reflex sympathetic dystrophy^{27,28}. There is some disagreement regarding the precise frequency at which this inhibitory response occurs²⁹.

Several authors report confidently that low-frequency currents can also be used to stimulate the autonomic system selectively^{15,30,31}.

Interferential therapy can benefit patients with both stress and urge incontinence although the causes of each differ. Stress incontinence results from an incompetent urethral sphincter mechanism, whilst urge incontinence arises from a disinhibition of the detrusor muscle. Patients showing stress incontinence, urge incontinence, or both, and treated with interferential therapy at 0–100 Hz for 15 minutes on three days per week reported decreased frequency of micturition³². Extensive studies conducted by Laycock and Green¹⁵ were designed to identify precisely the optimum frequency of stimulation, and position of the electrodes, for the treatment of incontinence. Drawing upon results obtained using animals³³, they concluded that stress incontinence should be treated at 10–50 Hz for 15 minutes. Initially such stimulation should cause the external urethral sphincter to close by a direct action upon the slowly conducting pelvic sympathetic nerves. An additional treatment at the higher frequency excites maximally the perineal branch of the pudendal nerve (which has a conduction velocity that lies in the slow to medium range, depending upon the twitch speed of the

muscle fibre that it innervates) and hence recruits all elements of levator ani.

Urge incontinence is treated at 5–10 Hz for 30 minutes, the lower rate of stimulation representing an attempt to excite small afferent fibres in the pudendal nerve that have a slow conduction velocity. This will produce reflex inhibition of detrusor following contraction of the slow twitch pelvic floor muscles. A clinical evaluation of these regimes is not yet available. Other workers have failed to identify a role for interferential therapy in the treatment of anorectal incontinence³⁴.

Control of circulation and reducing oedema

Several studies investigate changes in the rate of blood flow following transcutaneous electrical nerve stimulation. Stimulation applied to the dorsal roots or spinal segment of origin of a peripheral nerve causes peripheral vasodilatation in the structures innervated by it³¹. Sufferers from Raynaud's syndrome treated for eight minutes at 90–100 Hz in the region of the stellate ganglion in the neck showed a doubling of pulse volume in the digital vessels²⁶. Nikolova-Troeva³⁵ demonstrated a similarly marked symptomatic improvement in patients with endarteritis obliterans who failed to respond to chemical sympathectomy or medication. Supporting these findings is a report that those with a peripheral vascular disease benefit from interferential therapy at 0–100 Hz for 10 minutes³⁶, although recent investigations cast doubt on the reproducibility of these effects^{30,37}.

Interferential therapy at a frequency of 100 Hz is recommended for the reduction of acute oedema. Such stimulation will activate the musculoskeletal pump and inhibit sympathetic activity, thus assisting the drainage of fluid from the affected area. Interferential currents also appear to have a direct effect upon the cell membrane and reduce the escape of intracellular fluid⁵.

Chronic oedema is treated optimally using a two-stage application. Initially the current is applied at 100 Hz to promote vasodilation. This is followed by a treatment at 10 Hz which activates the musculoskeletal pump to remove fluid that has returned to the venous and lymph channels.

Evidence supporting the use of interferential therapy in the control of oedema appears mainly anecdotal, although in most textbooks this still appears as an indication^{4,5,10}.

Effects upon cell metabolism and the healing process

In addition to those effects described above, the electrical stimulation of tissue appears to exert other, more subtle, influences. Treatment with interferential current alters the intracellular concentration of enzymes and other molecules that are important in many metabolic processes. The literature contains reports of changes in the titre of cyclic adenosine monophosphate³⁸, acetylcholine esterase, alkaline phosphatase³⁹, and lysosomal enzymes⁴⁰. Such observations may help to explain the effects of

interferential therapy that are as yet understood poorly, such as the acceleration of bone healing⁴¹ and the repair of nerves³⁹, tendons and ligaments⁴², and improved regeneration of the liver⁴⁰. Further consideration of this topic is beyond the scope of the present work and the interested reader is referred elsewhere⁴²⁻⁴⁵.

The use of electric currents to promote the healing of bone currently enjoys considerable interest. An extensive literature attends this topic and again the interested reader is referred to recent reviews for further information⁴⁶⁻⁴⁸. Interferential therapy is still little used in this capacity, although good results are claimed in the treatment of acute fractures of the tibia and fibula at 20 Hz for 20 minutes on five days per week⁴⁹. The same author reports a beneficial effect, on the basis of empirical observations, in cases of delayed or non-healing. Interferential therapy at 20 Hz for 20 minutes improved the union of mandibular fractures⁴⁹, and at 100 Hz for 20 minutes accelerated the resolution of Sudeck's atrophy and pseudoarthrosis⁵⁰. The rate of callus formation and subsequent mineralization resulting from fractures induced experimentally in the radius and ulna was more rapid in animals treated with interferential therapy⁵¹.

Therapy in neurological impairment

Spasticity resulting from a cerebrovascular accident was suppressed by the stimulation of groups of muscles antagonistic to those in spasm. This was achieved using an interferential current alternating at 50 Hz, and although the spasticity returned after one hour, useful progress in rehabilitation was possible during this period⁵². Chronic electrical stimulation for eight hours daily at 10 Hz helped to reverse neuropathic changes caused by diabetes in rats, and may indicate a method by which vulnerable nerves might be protected⁵³.

Conclusion

Interferential current therapy is used widely to stimulate tissues that lie deep within the body. The effects can be local or more general depending upon the configuration of the current applied to the skin. Unlike other methods of low-frequency electrical stimulation, these currents encounter a low electrical resistance and can thus penetrate deeply without causing undue discomfort.

Several physiological effects clearly occur during interferential current therapy, although reliable clinical studies seeking to evaluate the claimed therapeutic benefits are reported infrequently.

Research suggests that interferential therapy can effectively stimulate voluntary muscle, promote peripheral blood flow, and accelerate bone healing. Empirical observations support a case for using this technique to reduce pain and control incontinence. Interferential therapy would seem to represent a valuable adjunct to the medical and physiotherapy management of the pathologies seen frequently by those specializing in sports medicine. As research

continues to clarify the precise characteristics of the current required to treat these various types of lesion successfully, interferential therapy will continue to grow in importance as a versatile and effective approach to therapy.

References

- 1 Hogenkamp, M., Mittelmeijer, E., Smits, I. and Van Stralen, C. *Interferential Therapy* B.V. Enraf-Nonius 1987, Delft, Holland
- 2 Kloth, L. Interference current. In: *Clinical Electrotherapy* Nelson, R.M., Currier, D.P. (Ed.) Ch 9, 183-207, Appleton and Lange, 1987. Norwalk, Connecticut, USA
- 3 Ward, A.R. *Electricity Fields and Waves in Therapy* Science Press, 1980. Marrickville, NSW, Australia
- 4 De Domenico, G. *Basic Guidelines for Interferential Therapy*. Theramed Books, 1981. Ryde, NSW, Australia
- 5 De Domenico, G. *New Dimensions in Interferential Therapy: A Theoretical and Clinical Guide*. 1st Edn Reid Medical Books, 1987, Lindfield, NSW, Australia
- 6 Treffene, R.J. Interferential fields in a fluid medium *Aust J Physiother* 1983, **29** (6), 209-216
- 7 Szehi, E. and David, E. The stereodynamic interferential current - a new electrotherapeutic technique *Electromedica* 1980, **48**, 13-17
- 8 Ganne, J.M. Interferential therapy *Aust J Physiother* 1976, **22** (3), 101-110
- 9 Savage, B. *Interferential Therapy*. Faber and Faber 1984, London
- 10 Wadsworth, H. and Chanmugam, A.P.P. *Electrophysical Agents in Physiotherapy*. 2nd Ed. Science Press, 1983. Marrickville, NSW, Australia
- 11 Herbert, K., Bowcock, S.A., Oakley, S. and Cooke, E.D. Interferential therapy in patients on oral anticoagulants *Physiotherapy* 1985, **71** (12), 521
- 12 Krnjevic, K. and Miledi, R. Failure of neuromuscular propagation in rats *J Physiol* 1958, **140**, 440-461
- 13 Brown, G.L. and Burns, B.D. 1985, Fatigue and neuromuscular block in mammalian skeletal muscle *Proc R Soc Lond* 1949, **136** 182-195
- 14 De Domenico, G. and Strauss, G.R. Motor stimulation with interferential currents *Aust J Physiother* 1985, **31** (6), 225-230
- 15 Laycock, J. and Green, R.J. Interferential therapy in the treatment of incontinence *Physiotherapy* 1988, **74** (4), 161-168
- 16 Walmsley, R.P., Letts, G. and Vooy, J. A comparison of torque generated by knee extension with a maximal voluntary contraction vis-a-vis electrical stimulation *J Orthop Sports Phys Ther* 1984, **6** (1), 10-17
- 17 Nikolova-Troeva L. The effect of interference current in neuritis nervi facialis *Arztl Praxis* 1966, **18** (13), 520-521
- 18 Eigler, E. Success achieved by treatment with interferential current on patients with epicondylitis humeri. *Proceedings of the 84th Congress of the German Society of Physical Medicine and Rehabilitation* 1979, Hannover, FRG
- 19 Melzack, R. and Wall, P.D. Pain mechanisms: a new theory *Science* 1965, **150**, 971-979
- 20 Wall, P.D. The discovery of transcutaneous electrical nerve stimulation *Physiotherapy* 1985, **71** (8), 348-358
- 21 De Domenico, G. Pain relief with interferential therapy *Aust J Physiother* 1982, **28** (3), 14-18
- 22 Watson, J. Pain mechanisms: a review. 3. Endogenous pain mechanisms *Aust J Physiother* 1982, **28** (2), 38-45

- 23 Taylor, K., Newton, R.A., Personius, W.J. and Bush, F.M. Effects of interferential current stimulation for treatment of subjects with recurrent jaw pain *Phys Ther* 1987, **67** (3), 346–350
- 24 Nikolova-Troeva, L. Interference current therapy in distortions, contusions and luxations of the joints *Munch Med Wochensh* 1967, **109** (11), 579–582
- 25 Truscott, B. Interferential therapy as a treatment for classical migraine: case reports *Aust J Physiother* 1984, **30** (1), 33–35
- 26 Schoeler, H. Physical block of the sympathetic chain *Technik im der Medizin* 1975, **1**. Deutsche Nemectron
- 27 Kaanda, B. Vasodilation induced by transcutaneous nerve stimulation in peripheral ischaemia (Raynaud's phenomenon and diabetic polyneuropathy) *Eur Heart J* 1982, **3**, 303–314
- 28 Wang, J.K., Johnson, K.A. and Ilstrup, D.M. Sympathetic blocks for reflex sympathetic dystrophy *Pain* 1985, **23**, 13–17
- 29 Wong, R.A. and Jetter, D.U. Changes in sympathetic tone associated with different forms of transcutaneous electrical nerve stimulation in healthy subjects *Phys Ther* 1984, **64** (4), 478–482
- 30 Bergslien, O., Thoresen, M. and Odemark, H. The effect of electrotherapy on human peripheral circulation *Acta Physiol Scand* 1985, **123**, 35A
- 31 Dooley, D.M. and Kasprak, M. Modification of blood flow to the extremities by electrical stimulation of the nervous system *South Med J* 1976, **69** (10), 1309–1311
- 32 Dougall, D.S. The effects of interferential therapy on incontinence and frequency of micturation *Physiotherapy* 1985, **71** (3), 135–136
- 33 Ohlsson, B., Lindstrom, S., Erlandson, B-E. and Fall, M. Effects of some different pulse parameters on bladder inhibition and urethral closure during intravaginal electrical stimulation: an experimental study in the cat *Med Biol Eng Comput* 1986, **24**, 27–33
- 34 Sylvester, K.L. and Keilty, S.E.J. A pilot study to investigate the use of interferential in the treatment of ano-rectal incontinence *Physiotherapy* 1987, **73** (4), 207–208
- 35 Nikolova-Troeva, L. The modern electrotherapeutic methods in the therapy of endarteritis obliterans *Ther Gegenw* 1968, **102**, 190–198
- 36 Belcher, J.F. Interferential therapy *NZ J Physiother* 1974, **6**, 29–34
- 37 Bergslien, O., Thoresen, M. and Odemark, H. The effects of three electrotherapeutic methods on blood velocities in human peripheral arteries *Scand J Rehabil Med* 1988, **20**, 29–33
- 38 Norton, L.A., Rodan, G.A. and Bourret, L.A. Epiphyseal cartilage cAMP changes produced by electrical and mechanical perturbations *Clin Orthop* 1977, **124**, 59–68
- 39 Nikolova, L. and Davidov, M. Influence of interferential current on enzyme activity of traumatized nerve (experimental study) *Vopr Kurortol Fizioter Lech Fiz Kult* 1978, **6**, 54–57
- 40 Nikolova, L.T., Popov, A.A., Kloucheck-Popova, E.F. and Apostolov, I.Tz. D-Galactosamine induced hepatitis: morphological and enzyme biochemical changes by interferential currents and low-frequency magnetic field *Physiotherapy* 1984 **70** (8), 301–305
- 41 Ganne, J.M. Stimulation of bone healing with interferential therapy *Aust J Physiother* 1988, **34** (1), 9–20
- 42 Stanish, W.D., Rubinovich, M., Kozey, J. and MacGillvary, C. The use of electricity in ligament and tendon repair *Phys Sports Med* 1985, **13** (8), 109–116
- 43 Geddes, L.A. A short history of the electrical stimulation of excitable tissue including electrotherapeutic applications *Physiologist* 1984, **27** (1), S1–S47
- 44 Newton, R. High-voltage pulsed galvanic stimulation: theoretical bases and clinical applications In: *Clinical Electrotherapy*. Nelson, R.M., Currier, D.P. (Ed.) Ch 8, 165–182. Appleton Lange, 1987. Norwalk, Connecticut, USA
- 45 Wu, K.T., Dennis, C. and Sawyer, P.N. Effects of electrical currents and interfacial potentials on wound healing *J Surg Res* 1967, **7**, 122–128
- 46 Bassett, C.A.L. The development and application of pulsed electromagnetic fields (PEMFs) for ununited fractures and arthrodeses *Clin Plast Surg* 1985, **12** (2), 259–272
- 47 Lilly-Masuda, D. and Towne, S. Bioelectricity and bone healing. *J Orthop Sports Phys Ther* 1985, **7** (2), 54–58
- 48 Petersson, C.J., Holmer, N.G. and Johnell, O. Electrical stimulation of osteogenesis *Acta Orthop Scand* 1982, **53**, 727–732
- 49 Ganne, J.M., Speculand, B., Mayne, L.H. and Goss, A.N. Inteferential therapy to promote union of mandibular fractures *Aust NZ J Surg* 1979, **49** (1), 81–83
- 50 Nikolova-Troeva, L. Physiotherapeutic rehabilitation in the presence of fracture complication *Munch Med Wochensh* 1969, **111** (11), 592–599
- 51 Laabs, W.A., May, E., Richter, K-D., Hohling, H.J., Althoff, J., Quint, P. and Hansjurgens, A. Knochenheilung und dynamischer interferenzstrom (DIC) — Erste vergleichende tierexperimentelle studie an schafen. Teil 1: Experimentelles vorgehen histologische ergebnisse *Langenbecks Arch Chir* 1982, **356**, 219–229
- 52 Alfieri, V. Electrical treatment of spasticity *Scand J Rehab Med* 1982, **14**, 177–182
- 53 Cameron, N.E., Cotter, M.A. and Robertson, S. Chronic low frequency electrical activation for one week corrects nerve conduction velocity deficits in rats with diabetes of three months duration *Diabetologia* 1989, **32**, 759–761